

LIGHTNING EFFECTS ON UNDERGROUND DISTRIBUTION CABLE USING
ALTERNATIVE TRANSIENT PROGRAM

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A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronics Engineering
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JULY 2015

ABSTRACT

Underground cable is commonly used in situation where power need to be transmitted across river or sea or through heavily populated areas. Even though underground cables are not directly exposed to hazard, lightning can induce a potential on the insulation of the underground cable. About 80% of the lightning strikes in Malaysia produce voltage in excess of 20 kV. This study was done to determine the possibility of having insulation breakdown of the underground cable either by direct stroke or by induction. The simulation was performed using Alternative Transient Program version of the Electromagnetic Transients Program (ATP-EMTP) software to determine whether the induced voltage due to lightning can cause any insulation breakdown. A network system consisting of 33kV Cu/XLPE/CWS/PVC/HDPE insulated armoured Polyvinyl Chloride (PVC) sheathed cable rated was modelled. A 40 kV lightning current with 1.2/50 μ s characteristic has been injected into the system. Several models cable and also soil to represent the whole system in electronic circuit have been designed and analyzed. This study shows the difference in various parameter across the shield and the sheath of the cable distribution of the best among the different types of armor and sheath used.

ABSTRAK

Kabel bawah tanah biasanya digunakan dalam keadaan di mana keperluan untuk menghantar kuasa ke seberang sungai, laut atau melalui kawasan berpenduduk padat. Walaupun kabel bawah tanah tidak langsung terdedah kepada bahaya voltan tinggi yang terhasil dari kilat tetapi ia juga boleh menyebabkan potensi pada penebat kabel bawah tanah. Kira-kira 80% daripada sambaran kilat di Malaysia menghasilkan voltan yang melebihi 20 kV. Kajian ini dilakukan untuk menentukan sebarang kemungkinan kerosakan pada penebat kabel bawah tanah sama ada dengan sambaran kilat secara langsung atau secara aruhan. Simulasi ini dilakukan dengan menggunakan perisian *Alternative Transient Program* versi *Electromagnetic Transients Program (ATP-EMTP)* untuk menentukan sama ada voltan yang disebabkan oleh kilat boleh menyebabkan apa-apa kerosakan pada penebat. Sistem rangkaian kabel yang terdiri daripada 33kV Cu / XLPE / CWS / PVC / HDPE kabel bereprisai dan bersarung Polivinil Klorida (PVC) dimodelkan. Arus 40 kV kilat dengan 1.2 / 50 ciri μ s telah disuntik ke dalam sistem. Beberapa model kabel dan tanah di hasilkan untuk mewakili keseluruhan sistem dalam litar elektronik yang telah direka dan dianalisis. Kajian ini menunjukkan perbezaan pelbagai parameter dalam mencari perisai serta sarung bagi kabel pengagihan yang terbaik di antara jenis perisai dan sarung yang digunakan.

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LIST OF SYMBOLS AND ABBREVIATIONS

a	-	Ampere
kA	-	Kilo Ampere
kV	-	Kilo Volt
Cu	-	Cuprum
$XLPE$	-	Cross link polyethylene
SWA	-	Steel Wire Armored
AWA	-	Aluminum Wire Armored
CWS	-	Copper Wire Screen
PVC	-	Polyvinyl Chloride
$HDPE$	-	High Density Polyethylene
Ω	-	Ohm
ρ	-	Resistivity
ϵ_o	-	Permittivity of Vacuum
ϵ_r	-	Relative Permittivity
μ_o	-	Permeability
l	-	Length
m	-	Meter
Z	-	Impedance
I	-	Lightning current amplitude
L	-	Inductance
r_{out}	-	Outside radius of insulation
ρ_s	-	Soil Resistivity
m^2	-	Meter square
$J(r)$	-	Current density at radius r (A/m^2)
T_{sta}	-	Time Start
T_{sto}	-	Time Stop

T	-	time
N	-	speed
s	-	seconds
A	-	Area
μ	-	Micro
r_{in}	-	Inside radius of insulation



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CHAPTER 1

INTRODUCTION

1.1 Project Overview

Underground or submarine cables is an effective method for the delivery of electricity across crowded areas or body of water such as river or sea to consumers other than using overhead lines. For some cases, it is impossible to accommodate for distribution using the overhead line system approach and as an option the underground cable become necessary to replace the overhead line system for transmission and distribution. The use of underground cables is the other method because it is a high cost during installation but reduces maintenance costs. In addition to the advantages of underground cables can also avoid the occurrence of such heavy snow and thunderstorms which may cause damage if used on the overhead line. Underground cables suitable for urban areas because it is hidden from the high-rise buildings in addition to reducing the area for installing poles for overhead lines.

Lightning strike is a known and most powerful electrostatic in nature. Any lightning strike is initializing with the polarization of positive and negative charges within a storm cloud. Subsequently, the polarization generates electric field surrounding the cloud. When the electric field generated is strong enough, it will ionize and make the air become conductive. With the conductive air, charges in the cloud can be transfer to the ground and hence lightning strike occur. Even though underground cables are not directly exposed to natural hazard such as lightning, it is such a way that lightning can induce

current and voltage into the cable. The effects of electric fields due to direct lightning strikes on ground to underground cable need to be considered.

1.2 Objectives of Project

The objectives of this study are as follows:

1. To design and model circuit that represent soil and underground cable;
2. To investigate the effects of lightning strike to ground on underground cable system over various condition due to its induced voltage And to underground cable at near, middle and far on the cable
3. To verify any possibility of having insulation breakdown or damage due to lightning induced voltage;

1.3 Problem Statement

The analysis was carried out on a 33kV Cu/XLPE/CWS/PVC/HDPE insulated armoured Polyvinyl Chloride (PVC) sheathed cable rated [1] underground cable. The single phase circuit has its sheath grounded with both-end-bonding method. There are undoubtedly many possible factors that can cause failure to the system but this analysis particularly intended to prove that lightning its induced voltages are the main reasons for the recently observed and reported insulation failure. Several factors such as the depth of buried cables, the type of soil, type of cable, cable layers must be taken into account to ensure that the analysis is running perfectly

1.4 Scope of Project

This project emphasizes on the voltage induced when 40,000 Volt lightning voltage injected into the aforesaid system designed. The 33000 Voltage rated underground cable system was modelled by taking into consideration all parameters involve. The analysis will be based on voltage induced due to lightning strike on ground for the determination of any possibility that can cause insulation failure or breakdown to the underground cable at 100 meter length. The effect will be focus on the mechanical protection such as armour and sheath.

1.5 Organization of Report

Generally this thesis can be divided into five chapters. The chapters are presented as follows:

Chapter I describes about project background, problem statement project's objectives and project's scopes as an introduction to this research project.

Chapter II consists of some theory background of this project such as lightning introduction, parameters of lightning, lightning components, underground cable characteristic, soil type and parameters, etc. Studies on literature review are needed in order to carry out the experiment and for the thesis writing's references.

Chapter III explains the experimental procedures and simulation studies. The method of the experiments will be presented in flow chart together with some brief explanations.

Chapter IV will analyse and discuss the experimental results of the research project. The results will be presented beginning with the analysing lightning effect to underground cable at near, middle or far based on the parameter

Finally, Chapter V will summarize and conclude all the results of the research project followed by some recommendations which will contribute for the future research.

1.6 Conclusion

This chapter describes about project background, problem statement project's objectives and project's scopes as an introduction to this research project. Organization of report also included in this chapter for easy use to reader whose want to refers this thesis.



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CHAPTER 2

EFFECT ON UNDER GROUND CABLE: A REVIEW

2.1 Introduction

Overvoltage is a condition where the voltage raised higher than it's rated. A transient overvoltage is a high voltage which has a rapid rise to the peak value and slowly decays to zero value [2]. Transient overvoltage can cause breakdown of insulation. A typical natural source of transient overvoltage events is lightning. Lightning is natural phenomena that accomplished by thunder which is very intense and unpredictable that can induce overvoltage. The current diffusion in the ground may also affect underground networks. When lightning strikes the ground, the discharge current diffuses uniformly into the surrounding soil. Soil type is also important in the impact of excess voltage where resistance in soil can reduce the resulting voltage of lightning to get to underground cables. In addition to the types of cable, underground cable depth grown can also reduce damage to the cable depends on soil resistivity

2.2 Lightning

Lightning was discovered by Benjamin Franklin [3] nearly 200 years ago. Lightning is the visible discharge of static electricity within a cloud, between clouds, or between tile earth and a cloud. Scientists still do not fully understand what causes lightning, but most experts believe that different kinds of ice interact in a cloud. Updrafts

in the clouds separate charges so that positive charges move and end up at the top of the cloud while negative flow to the bottom. When the negative charge moves down, a "pilot leader" is created. "This leader rushes toward the earth in 150-foot discrete steps, ionizing a path in the air." The final breakdown generally occurs to a high object the major part of the lightning discharge current is then carried in the return stroke which flows along the ionized path. An estimation that had been done by scientists that the earth is struck by lightning on the average of 100 times every second. Most lightning strike occurrences contain multiple strokes. 20% of these occurrences are only one stroke and 80% are two or more strokes, while the mean stroke is 5 to 6. The maximum that has been recorded is 26 but the most common number is 3 to 4 with the time interval between strokes of 40 ms.

According to Martin A. Uman [4], 90% of cloud-to-ground lightning initiated by downward moving negative charged leader while only 10% of the cloud-to-ground lightning are initiated by downward moving positive leader. After leader, there is an arc current travels from ground to thundercloud, called return stroke. After few tens of milliseconds, another leader will travel down and produce second return stroke and this process can be repeated for a number of times. The maximum return strokes recorded by Martin A. Uman are 26 strokes, while the most common number of return stroke are 3 to 4 strokes with a time interval between strokes is about 30 ms to 40 ms.

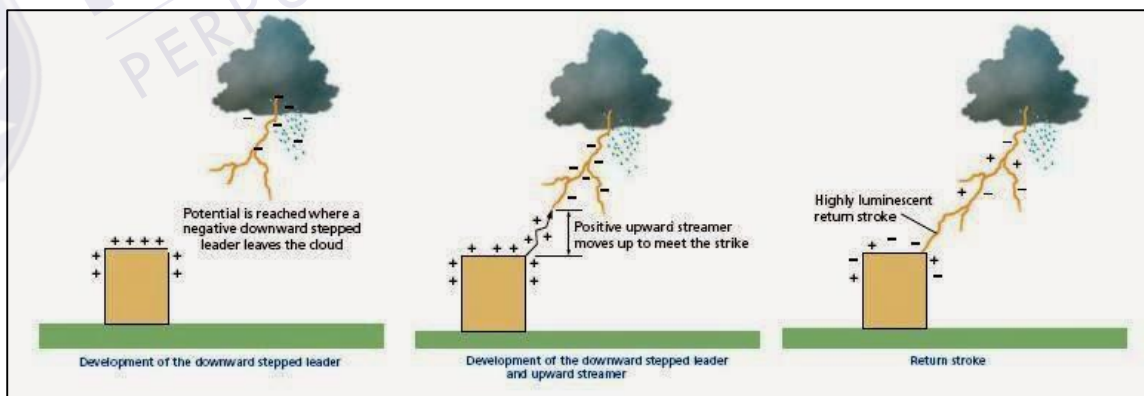


Figure 2.1 : Formation of Lightning

2.2.1 Definitions of Lightning

There are many definitions of lightning. Lightning can be explained from several perspectives with different references. Martin A. Uman [4] said lightning is a transient, high-current discharge whose path length is measured in kilometres. Lightning also occur when one part in atmosphere consist large electric charges which can lead to electric field and charge that can cause air breakdown. While Britannica Micropedia said lightning occurs when some region of the atmosphere attains an electrical charge of sufficient potential to cause dielectric breakdown of the air. Last but not least, from BS 6651 1992 said lightning is an electrical discharge between cloud and earth, of atmospheric origin, comprising one or more impulses of many kilo amps. The electric field strength in soils at a radius of r meters is given by the following equation, by determining of lightning current distributed in radius around lightning strike point in hemisphere [5, 6].

$$E(r) = \rho_s J(r) = \rho_s \frac{I}{2\pi r^2} \quad (2.1)$$

Where,

- ρ_s Soil resistivity (Ωm)
- $J(r)$ Current density at radius r (A/m^2)
- I Lightning current amplitude (A)

2.2.2 Direct and Indirect Lightning Strikes

Lightning causes damage because it generates electrical transients (very short-lived events) like overvoltage and power surges and strikes.

Direct lightning strikes can generate millions of volts and hundreds of thousands of Amps and high-level overvoltage transients. They may seriously a buildings' physical

structure, electric distribution system, and cause fires. And the electromagnetic pulse energy of a lightning strike can affect electrics and electronics 2 kilometres away.

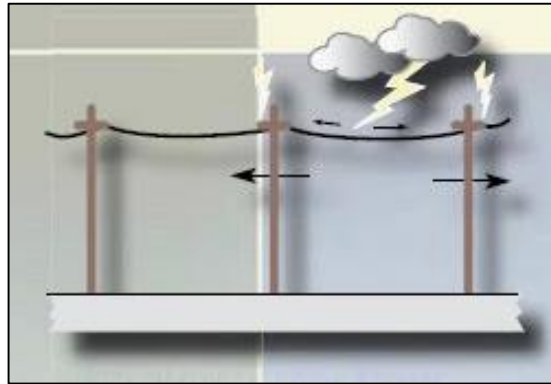


Figure 2.2: Direct lightning strike on overhead lines

Indirect lightning strikes are one, though not the only, cause of low-level transients. Strikes in the vicinity of a building and on power lines lead to overvoltage induced by the electromagnetic fields from the lightning current. Though typically less damaging than direct strikes, they are enough to melt electronic circuitry.



Figure 2.3: Indirect lightning strike

2.2.3 Standard Lightning Wave Shape

The breakdown or flash-over voltage of the electrical equipment with this wave shape are required to be equal or higher than the basic insulation level fixed and the spark over voltage and discharge voltage of the protecting devices. The Basic Lightning Impulse Insulation Level (BIL) are specified for the standard lightning impulse wave shape [7]. The general lightning impulse wave shape is illustrated in Figure below.

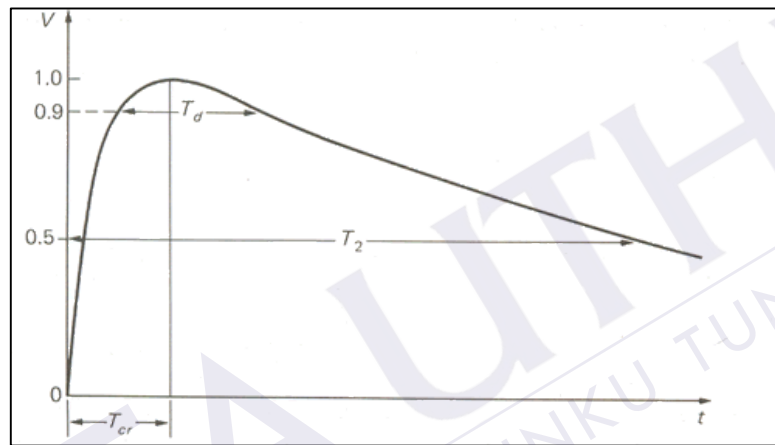


Figure 2.4: Lightning Impulse Wave Shape

BIL implies the limits up to which the insulator could withstand impulse due to lightning stroke. The front time and the tail time of the impulse is represented by T_{cf} and T_2 respectively. Front time is the interval between $t=0$ to the peak voltage or current. While tail time is the interval between $t=0$ to where the function amplitude has fallen 50% of its peak value. The standard lightning impulse wave shape is 1.2/50 μs which means 1.2 μs for the front time and 50 μs for the tail time [7].

2.3 Underground Cable

Underground distribution cables are a vital part of any power distribution system. Correct installation of cables will ensure a reliable electrical system with a long

operational lifetime and improved system security. To ensure a reliable underground cable network, care must be taken during the installation of the cables.

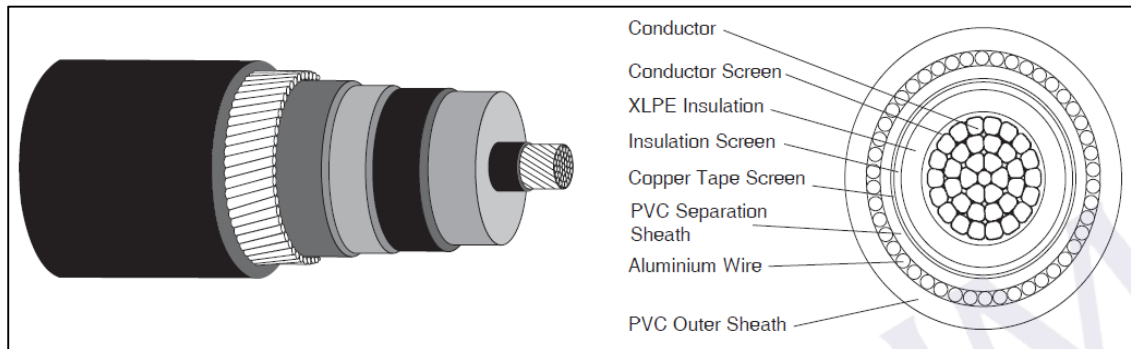


Figure 2.5: A side view and a cross section of cable [1]

Distribution of electricity is one of the core businesses, hence high efficiency and optimum use of cable properties in delivering electricity for powering the desired load is of upmost interest. The selected method of installation shall optimize the current carrying capacity or known as ampacity [8].

There are two mainly costs associated in choosing the right method of installation which are the initial cost and long-term cost. Initial cost consists of planning constructing and commissioning of the cable. Long-term cost includes any works that require direct access to the cable.

The selection of cable installation method shall meet the committed project duration. Short duration of project will require a less time consuming but reliable method of cable installation. Suitability and readiness of the installation methods for further works that require fast access to the cable during its operation and maintenance period shall also be deliberately weighed.

There were four types of installation systems that were studied in this study that are:

- a. Cable directly buried underground
- b. Cable laid inside duct bank
- c. Cable laid inside cable trench
- d. Cable laid inside tunnel

Based on the results, cable directly buried underground gives higher ampacity and the cost is less compare to other types of installation. However the option to choose it will depends on the local authority requirement [9].

2.3.1 Directly Buried Underground Cable Installation

Majority cables in Malaysia are directly buried 1.5 meter depth in the ground as shown in Figure 1. This type of installation is usually prone to third party digging which will lead to breakdown [9]. However, the safety of the cable is maintained by ensuring that the minimum distance between the underground cables with other service is 6 inches. Besides that, roads, ditches, railroads need to use glass ceramic pipes for added protection. The. Slab and brick installation in subsoil means there are underground cables that provide additional security in the event of third party cable makes excavation.

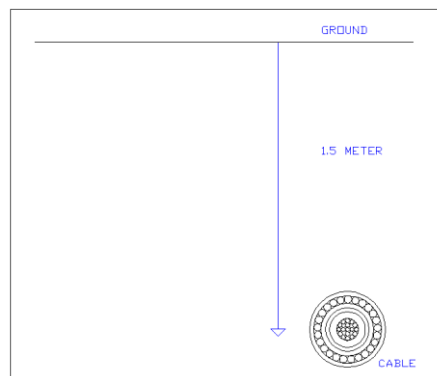


Figure 2.6: Cable laid directly buried underground [9]

A layer of sand should be planted around the cable before the original soil area is used for fine sand structure, easy to absorb moisture and high humidity (cold).

2.3.2 Underground Cable Parameters

The line equations are the same for underground or submarine cables and overhead lines because the parameters R' , L' , G' , C' per unit length are distributed along a cable in the same way as on an overhead lines.

$$-\left[\frac{dV}{dx}\right] = [R'(\omega) + j\omega L'(\omega)][I] \quad (2.1)$$

$$-\left[\frac{dI}{dx}\right] = [G'(\omega) + j\omega C'] [V] \quad (2.2)$$

Overhead lines are simple in geometry. There are more variations in underground and submarine cable geometries. Shunt conductance G' is negligible on overhead lines but in underground cable it is much larger and represents dielectric losses [10].

$$G' = \tan \delta \cdot \omega C' \quad (2.3)$$

The shunt capacitance C' is much larger than on overhead lines because the conductors core conductor, sheath etc.) are very close together. The value for inductance L' is small typically of L' overhead. While the value for C' is large which typically 20 times of overhead. The parameter L' and C' can be converted to surge impedance Z and wave speed c by the following equation [10].

$$Z = \sqrt{\frac{L'}{C'}} \quad (2.4)$$

$$c = \frac{1}{\sqrt{L'C'}} \quad (2.5)$$

Give typical values for underground cable

$$\begin{aligned} Z &\approx 30 \text{ to } 70 \, \Omega \text{ (1/10 of overhead line)} \\ C &\approx 160 \, 000 \text{ km/s (1/2 of overhead line)} \end{aligned}$$

The shunt capacitance for insulation between core conductor and sheath, or sheath and armour, or sheath and soil can be calculated using equation (2.6).

$$C' = \frac{2\pi\epsilon_0\epsilon_r}{\ln \frac{r_{out}}{r_{in}}} \quad (2.6)$$

Where;

- ϵ_0 Permittivity of vacuum
- ϵ_r Relative permittivity
- r_{out} Outside radius of insulation
- r_{in} Inside radius of insulation

Since C' of an underground cable is very large, it may be good enough to represent a “short” cable as a lumped capacitance, if the frequencies are not high.

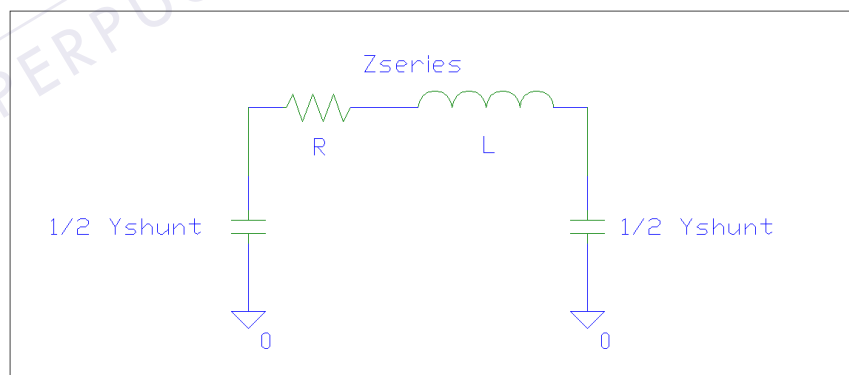


Figure 2.7: Underground cable circuit model

2.3.3 Material for sheath and armour cable

Mechanical protection is one of the layers contained in a cable. Sheath and shield is a material called mechanical protection where it is very important to protect the power cable of a cable of material or heavy vehicles such as trucks, concrete, etc. which can damage the cable. Many covers and shields made of metal materials that have the ability to carry an electrical current (conductor).

Many resistors and conductors have a uniform cross section with a uniform flow of electric current, and are made of one material. In this case, the electrical resistivity ρ (rho) is defined as:

$$\rho = \frac{RA}{l} \quad (2.7)$$

where

R is the electrical resistance of a uniform specimen of the material (ohms, Ω)

l is the length of the piece of material (meters, m)

A is the cross-sectional area of the specimen (meter square, m^2).

The reason resistivity is defined this way is that it makes resistivity an *intrinsic property*, unlike resistance. All copper wires, irrespective of their shape and size, have approximately the same *resistivity*, but a long, thin copper wire has a much larger *resistance* than a thick, short copper wire. Every material has its own characteristic resistivity – for example, resistivity of rubber is far larger than copper's.

Table 2.1: Resistivity of selected metal (sheath and armour) [11]

Metal	Resistivity, ρ (Ωm)
Aluminum	26.5×10^{-9}
Steel (plain)	180×10^{-9}
Copper	17.1×10^{-9}
Zinc	59×10^{-9}
Lead	208×10^{-9}
Iron	96.1×10^{-9}
Tin	115×10^{-9}

2.4 Soil

Soil covers much of the land on Earth. All soils are made up of sand, silt, or clay. This describes the particle sizes, not the type of parent material it is composed of. Parent materials are the types of rocks and minerals it is derived from. Soils have other components: air, water and organic matter (decomposing plants and animals). There are many types of soils, and each has different colours, textures, structure and mineral content. The depth of the soil also varies. Each type of soil has a resistivity, permeability and permittivity that affect the underground cable. Figure 2.3 show a few example type of soil.

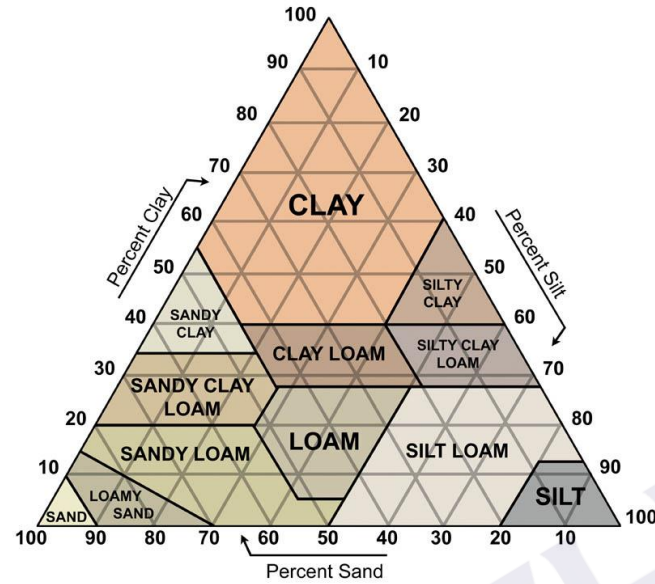


Figure 2.8: An example type of soil textural triangle

2.4.1 Soil Model in the Form of an Electrical Circuit

Soil resistivity testing is the process of measuring a volume of soil to determine the conductivity of the soil. The resulting soil resistivity is expressed in ohm-meter or ohm-centimetre.

Soil resistivity testing is the single most critical factor in electrical grounding design. This is true when discussing simple electrical design, to dedicated low-resistance grounding systems, or to the far more complex issues involved in Ground Potential Rise Studies (GPR). Good soil models are the basis of all grounding designs and they are developed from accurate soil resistivity testing.

2.4.2 Wenner Soil Resistivity Testing and Other 4-Point Tests

The Wenner 4-point Method is by far the most used test method to measure the resistivity of soil. Other methods do exist, such as the General and Schlumberger methods, however they are infrequently used for grounding design applications and vary only slightly in how the probes are spaced when compared to the Wenner Method.

An alternative to the exponential equation of the IEC standards is proposed in [12] and [13] to model the soil. The underlying idea is to subdivide the soil surrounding the cables into several concentric layers. Each soil layer is represented with its RC thermal T equivalent circuit (Fig. 2.9) to be compatible with the IEC standards [14], [15]. The soil model parameters are computed from the thermal resistivity, the heat capacity of the soil, and the dimensions of each layer using the following formula [16]

$$\rho = \frac{4\pi AR}{1 + \frac{2A}{\sqrt{(A^2 + 4B^2)} - \sqrt{(A^2 + B^2)}}} \quad (2.8)$$

$$C = \epsilon_r(\text{soil}) \times \epsilon_0(\text{free sapce}) \quad (2.9)$$

Where ρ is the thermal resistivity of the layer under study, R resistance, B depth of probe, A spacing of probe, respectively, and C is the heat capacity of the material. However, note that in this paper, R is used as the symbol for thermal resistances where the IEC standards use T . Each layer is represented with a T equivalent circuit, as shown in Fig. 2.9 [17]

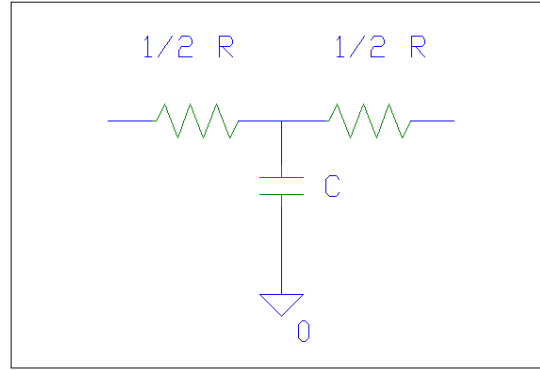


Figure 2.9: Equivalent electro thermal circuit (T equivalent circuit) used for each of the individual layers modelled

The physical discretization of the soil can be observed, where the T equivalent circuits representing each layer are illustrated. The values of R and C in the circuit are defined in (2.8) and (2.9). Once the equivalent resistances and capacitances are calculated for each layer, the RC ladder of the soil can be constructed by concatenating all the T equivalent sub circuits into a complete ladder model.

2.4.3 Soil Resistivity and Factors Affecting Soil Resistivity

Soil resistivity varies widely by region due to differences in soil type and changes seasonally due to variations in the soil's electrolyte content and temperature. Therefore, it is recommended that these variations be considered when assessing soil resistivity. The resistivity of soil is primarily determined by the soil's electrolyte contents. Electrolytes consist of moisture, minerals, and dissolved salts.

Table 2.2: Soil resistivity for various soil type [18]

Soil Type	Resistivity (Ω -cm)		
	Minimum	Average	Maximum
Ashes, brine or cinders	590	2,370	7,000
Concrete (below ground)	-	3,000	-
Clay, gumbo, loam or shale	340	4,060	16,300
Clay, gumbo. Loam or shale with varying portions of sand and gravel	1,020	15,800	135,000
Gravel, sand or stone with little clay or loam	59,000	94,000	458,000

In general, soil resistivity decreases (improves) as electrolytes increase. Because the resistivity of soil is directly affected by its moisture content and temperature, it is reasonable to conclude that the resistance of any grounding electrode system will vary throughout the different seasons of the year. Temperature and moisture content both become more stable as distance below the surface of the earth increases.

2.5 Conclusion

This literature review chapter explained all about the important lightning strike on the earth threw to the underground cable. The definition of lightning has been describe for all the reader. Type of underground cable, soil and buried of cable also be told in this chapter.

CHAPTER 3

EMTP MODEL FOR SIMULATION

3.1 Introduction

Now day many computer simulations software package are created by individual or company to analysis of the transient overvoltage becomes more accurate, efficient and easy. Transient overvoltage studies on underground cable due to lightning strike are very important to determine any possibility of having insulation failure or breakdown. The selection of suitable simulation software according to the supporting model and analysis of the project will facilitate the work for designing the model, running the simulation and analysis of the result. Running and executing this simulation only take small amount of time but deciding on the parameters of the components and circuit models representation for source, cable and soil are the actual challenge when performing the analysis. The correct and accurate model design is essential to ensure reliability of the analysis. The parameters setting for models used in the simulation are very important since the simulation result depends on the data and circuit model.

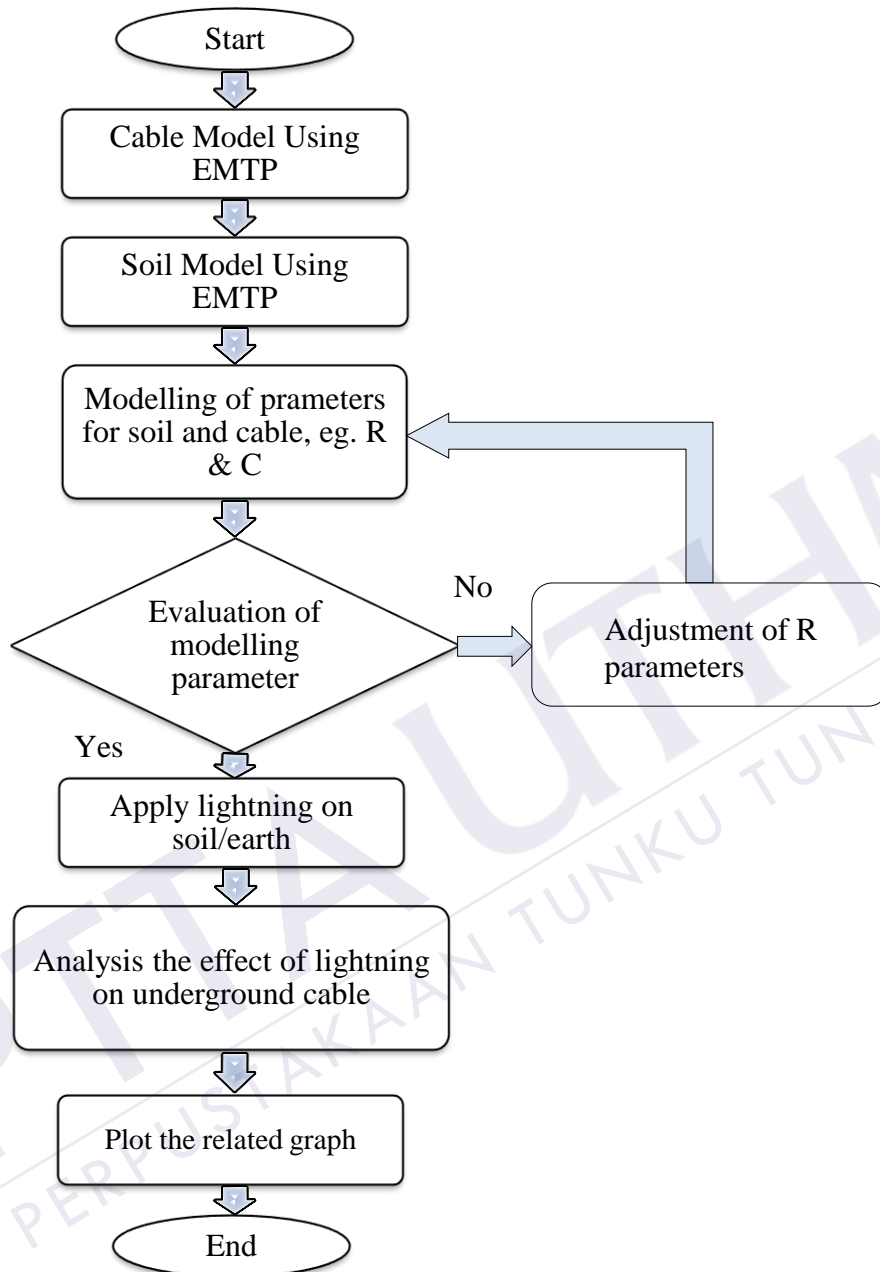


Figure 3.1: Flowchart of the analysis

3.2 Digital Simulation Program

The Alternative Transient Program (ATP) and Electromagnetic Transient Program (EMTP) are one of the most widely used software by electric power industry for digital simulation of electrical system transient phenomena of electromagnetic as well as electromechanical nature in electric power systems. ATP program is a powerful tool for modelling power system transients [6]. The Alternative Transient Program version of the Electromagnetic Transients Program (ATP-EMTP) is an integrated engineering software tools that have been used world-wide for switching and lightning surge analysis, insulation coordinate on studies and etc. ATP Draw is a graphical pre-processor to the ATP version of the EMTP. ATP Draw has a standard Windows layout and offers a large Windows help file system. User can build up the electric circuit in the program by selecting predefined components from an extensive palette.

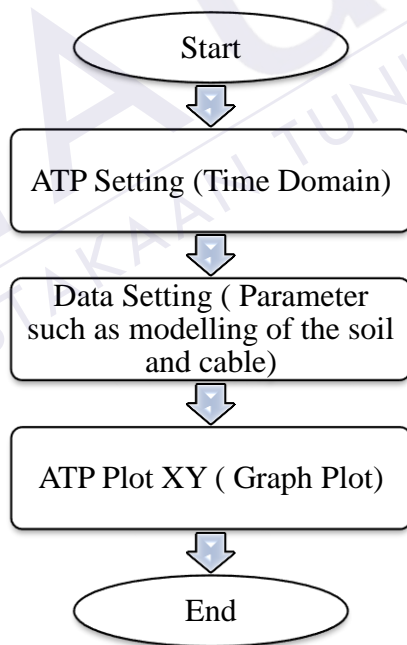


Figure 3.2: ATP Flowchart

3.3 System Configuration

The system consists of a 33kV Cu/XLPE/CWS/PVC/HDPE insulated armoured Polyvinyl Chloride (PVC) sheathed cable rated [1] underground cable with a length of 100 meters buried underground at a depth of 1.5 and 2.0 meters. The cable dimensions are illustrated in the Figure 3.3 below.

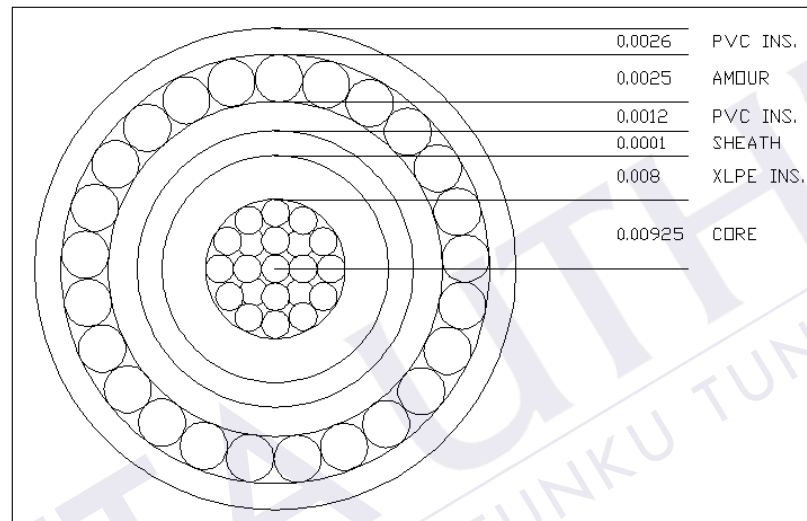


Figure 3.3: Layer name and thickness of the cable

3.3.1 Lightning source

The lightning source represent by surge function of Heidler type 15 in ATP. The source can be selected by setting the current or voltage refer to our priority.



Figure 3.4: Heidler type source

The Figure 3.5 shown that detail component heidler where we can setting to create the lightning waveform base on the original data such as 1.2/50 μ s. T_f is the front duration time in seconds which is the interval between t=0 to the function peak. The stroke duration which is the interval between t=0 to the point on the tail where the function amplitude has fallen 50% of its peak value is represented by tau in seconds. Tsta is the starting time in seconds, Tsto is the ending time also in seconds and n is the factor influencing the rate of rise of the function. The maximum steepness will be increased if the value of n increase.

DATA	VALUE
Amp	40000
T _f	1.2E-6
tau	5E-5
n	2
Tsta	0
Tsto	1

NODE	PHASE	NAME
HEI	1	

Group No: 0 Edit1 Label: U

Comment:

Type of source
☐ Current
☒ Voltage

☐ Hide
☐ Lock

OK Cancel Help

Figure 3.5: Component heidler window

The lightning surge waveform is characterized by a rise time of 1.2 μ s and a half-value (50%) time of 50 μ s, which are typical values for lightning strikes. The lightning surge current wave shape as shown in Figure 3.6 below is injected at the ground above the cable.

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